Modulus Deficit in
Thin Film Copper Electrodeposits:
Experiments and Modeling

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http://www.boulder.nist.gov/div853/DTR/DTR.htm
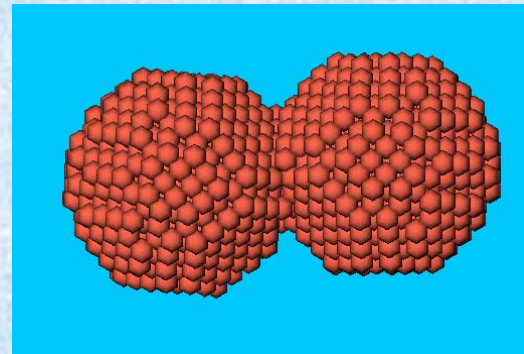
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Outline, 1/2

I will describe numerical experiments, based on SEM observations, that may point toward a mechanism for this modulus deficit.

Introduction --   Experiments

SEM observations

Numerical models

Results

Discussion   --   What's the mechanism?

Conclusions –   Trends of numerical results are in the right
direction, and appear large enough to
explain the effect – mechanism appears to be "load
shedding"

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# Outline, 2/2

Acknowledgments:

- NIST for funding, including Office of Microelectronics Programs

- Colleagues Roy Geiss for SEM, and Yi-Wen Cheng and Joyce Wright for mechanical testing

- Prof. Jon Rifkin of U. of Connecticut for MD code XMD

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Introduction, 1/2

Microtensile tests of metal thin films (0.5 to 10 µm thick, physical vapor deposited, sputtered, or electrodeposited) generally produce low values of Young's modulus (**10 s of percent**), relative to the bulk polycrystalline average of reference values. (ref Huang and Spaepen, *Acta Met.* **48**, 2000, 3261-3269, my previous results, etc.)

- Microtensile tests done by the same techniques, for some other materials, give the "expected" value: epitaxial Si, CVD Poly Si

Electroplated copper
thickness: 2.59 µm
strain rate: 6.79×10^{-5} s^{-1}
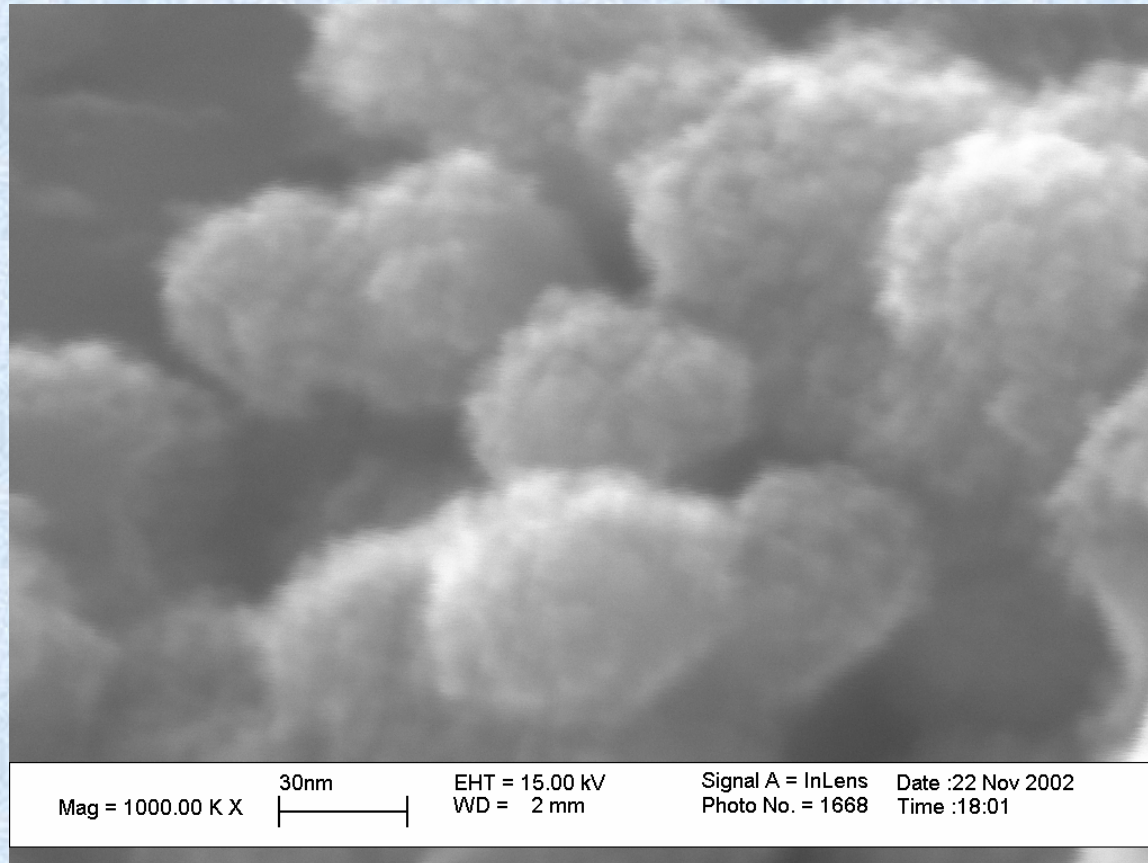room temperature

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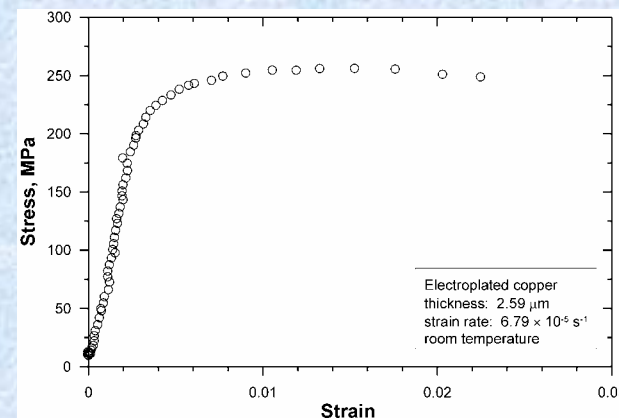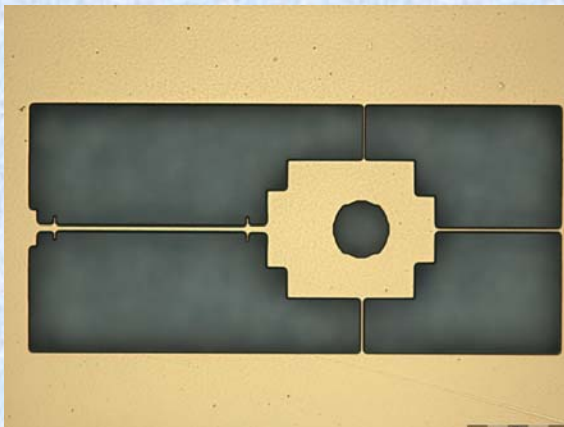
Introduction, 2/2

- A variety of mechanisms for the modulus deficit are suspected, under the general heading of anelasticity.

- Important to understand because:
  the modulus value is basic to mechanical design;
  getting the modulus right is basic to mechanical testing.

- Measurements of the elastic properties of thin films have an "interesting" history---these are difficult measurements.

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High-resolution SEM of electrodeposited copper

Mag = 1000.00 K X   30nm   EHT = 15.00 kV   Signal A = InLens   Date :22 Nov 2002
WD = 2 mm   Photo No. = 1668   Time :18:01

Micrograph at 1 M X clearly shows loosely aggregated spheroids, diameter approximately 30-50 nm, with possible substructure

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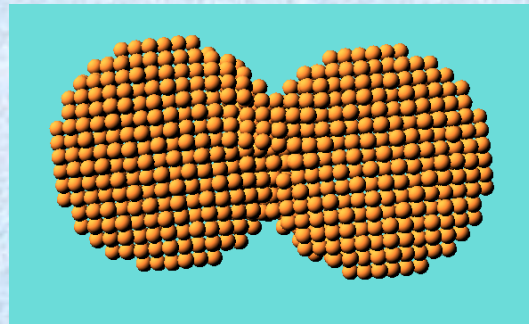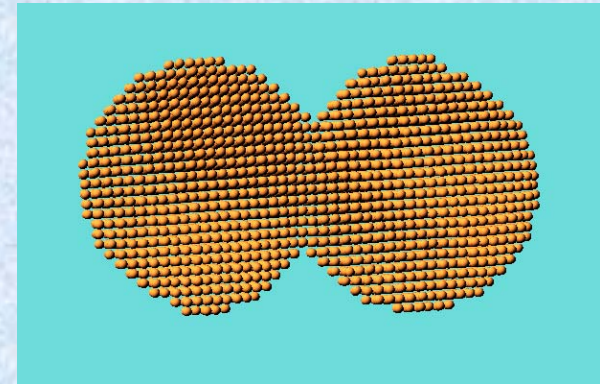# Modulus Deficit in Thin Film Copper Electrodeposits: Experiments and Modeling
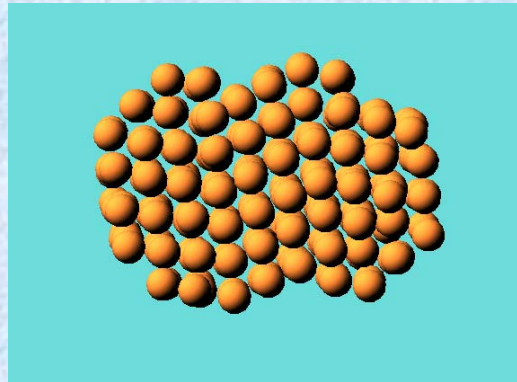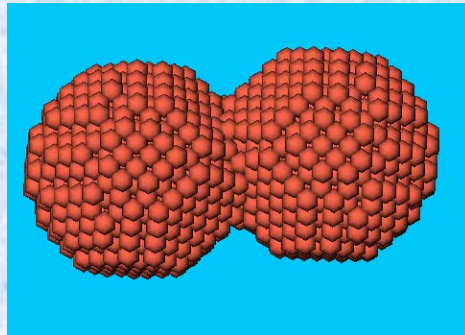
Atoms per initial sphere

140

3604

456
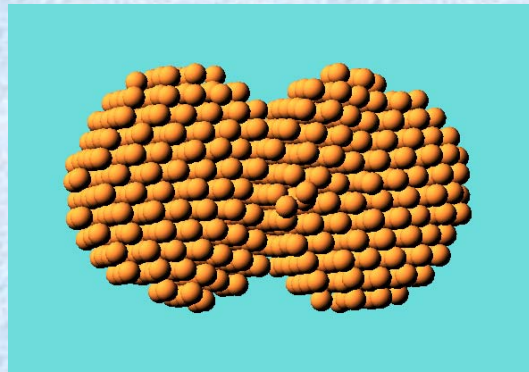
8628

1088
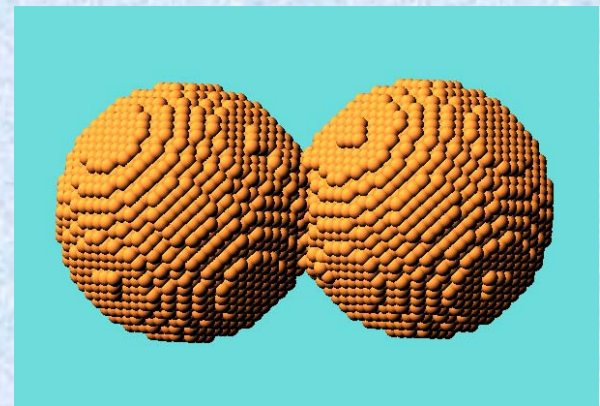
Size effect in metal sphere aggregation, 0 K
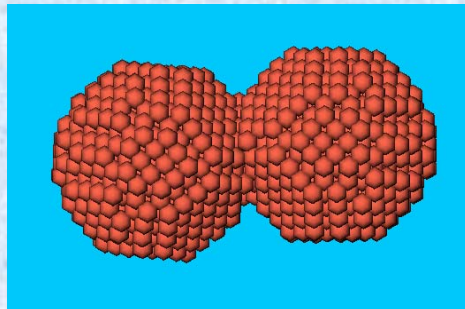
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Results after 9×10^{-12} s (9 picoseconds):

Temp., K:
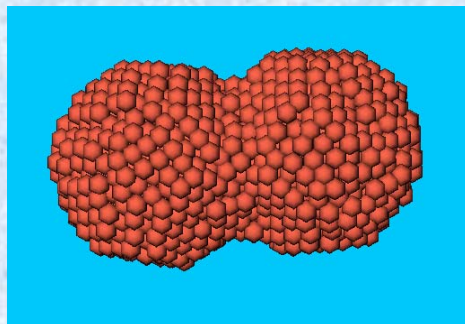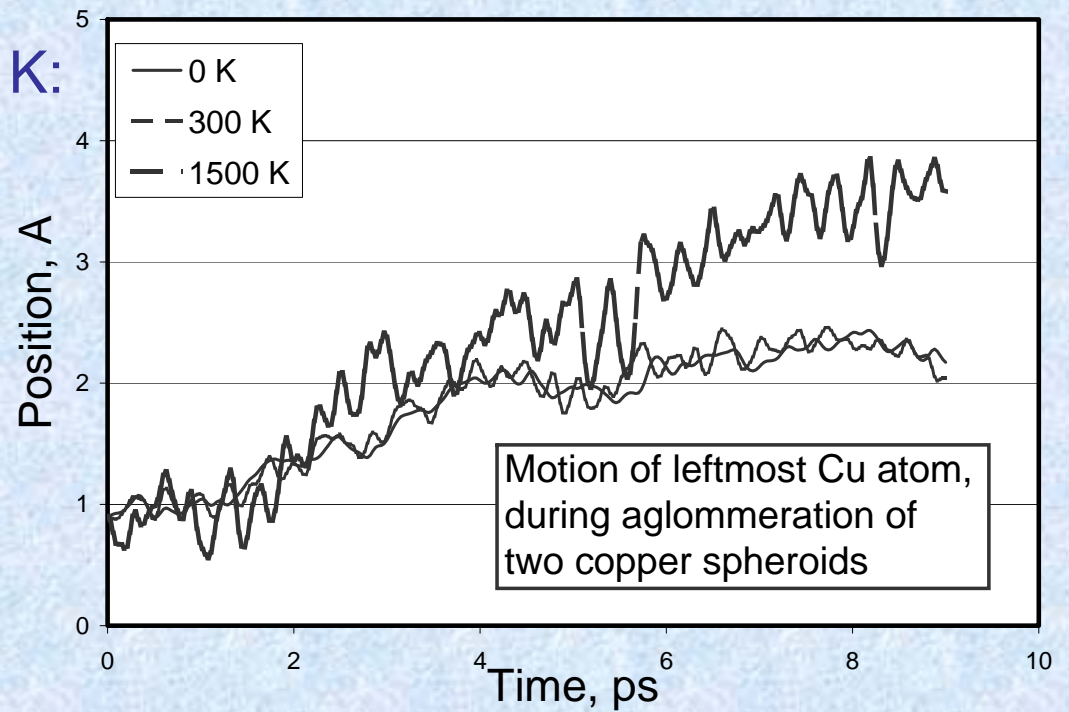
0

300

1500

Legend:
— 0 K
-- 300 K
— 1500 K

Position, A (y-axis)
Time, ps (x-axis)

Motion of leftmost Cu atom, during aglommeration of two copper spheroids

Result: Spheroids can aggregate at room temperature without electrical forces or solvent effects

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Numerical models: Chains of spheres

3 types:

    <100>

    <110>

    <111>
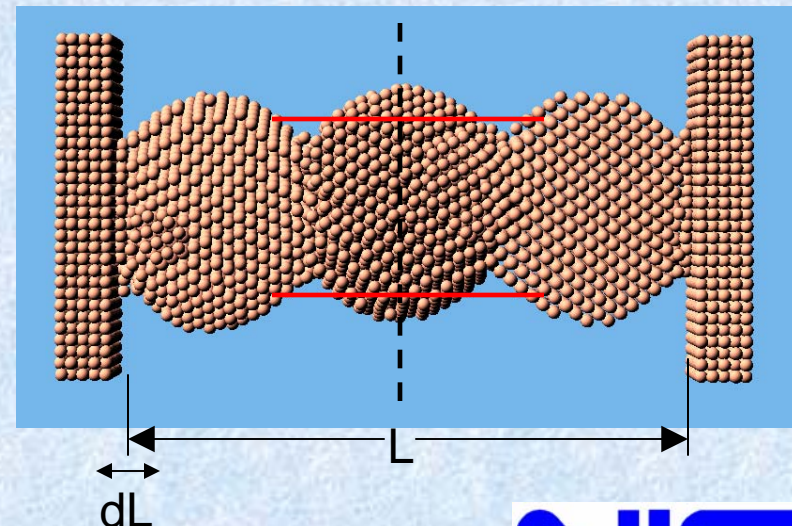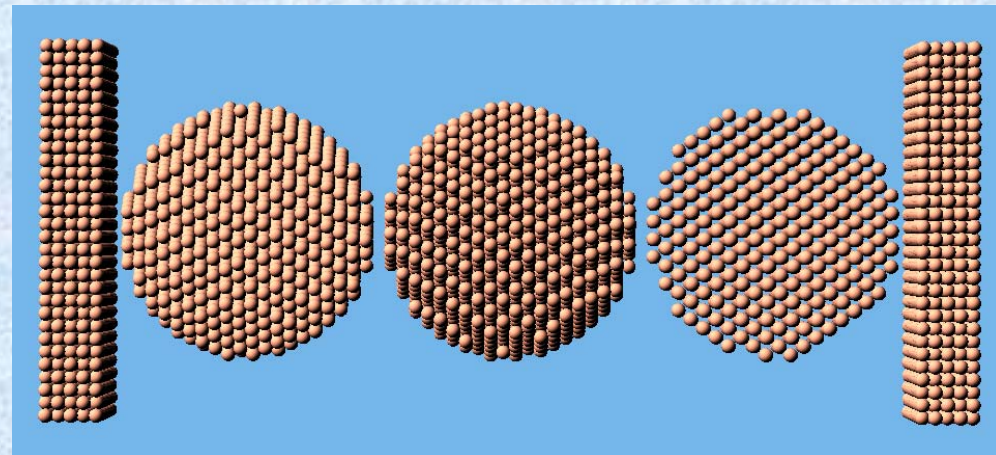
Along tensile axis

Various twist angles

Around 2000 atoms per sphere, at 300 K

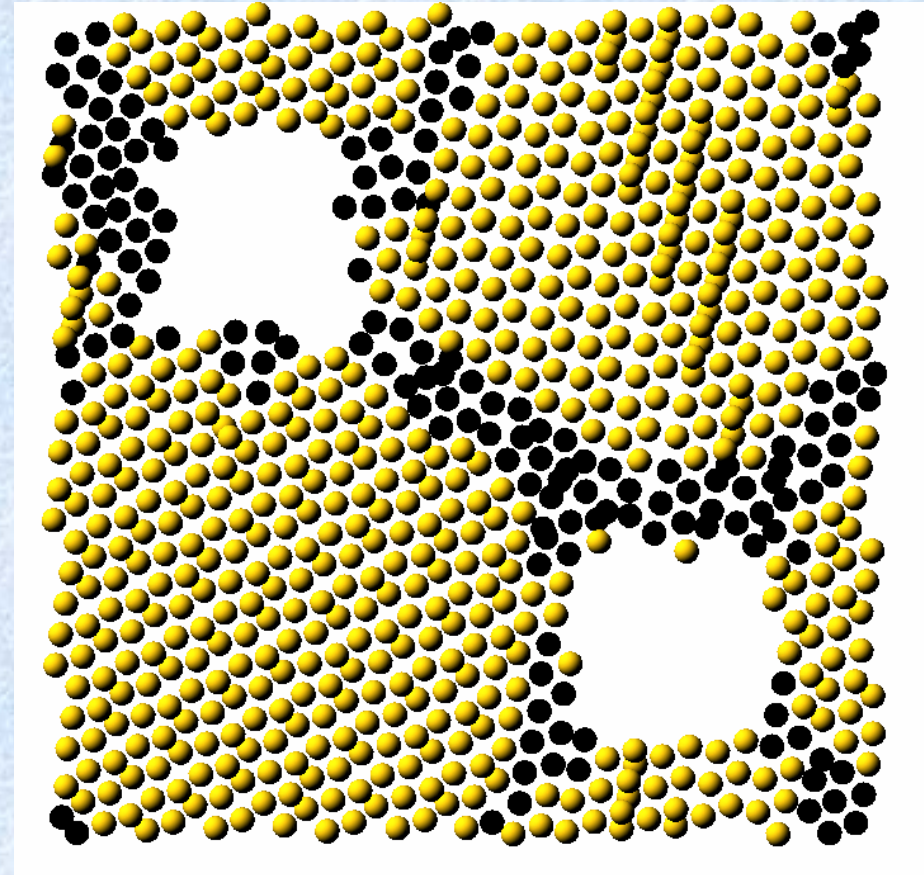Many-body EAM potential after Mei and Fernando (*Phys Rev B* **43**, 1991, 4653-4658)

Periodic Boundary Condition (PBC) model

FCC array of spherical clusters of atoms
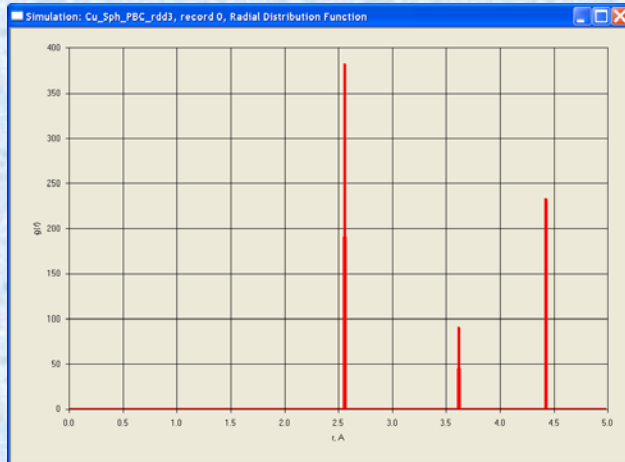
Self-assembled at 300 K

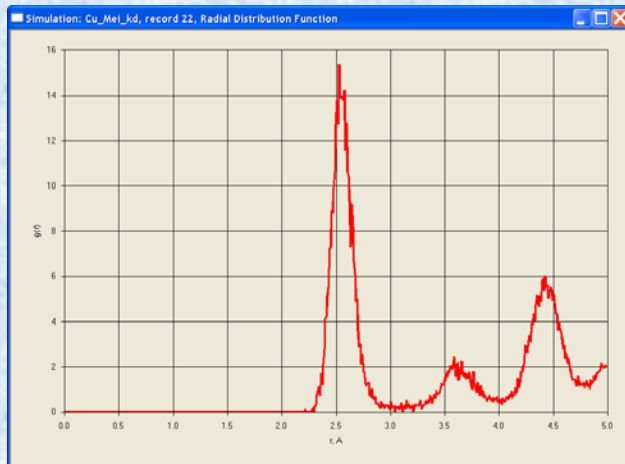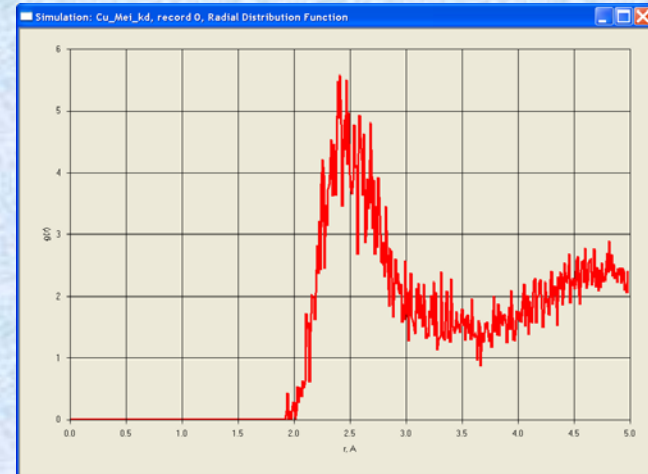Colored: High FCC symmetry

Black: Low FCC symmetry

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Radial distribution functions (RDF) for various models
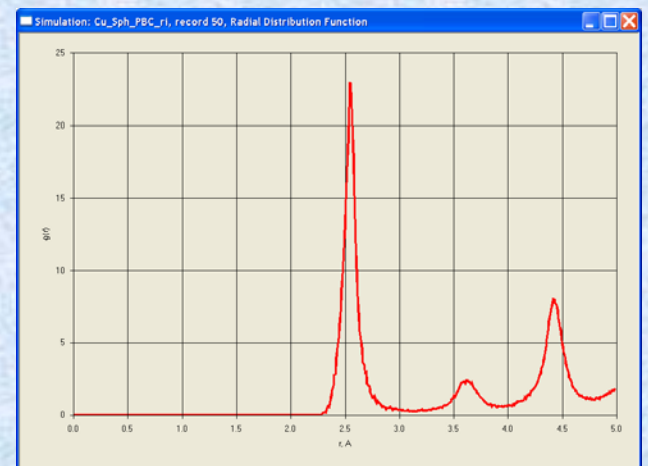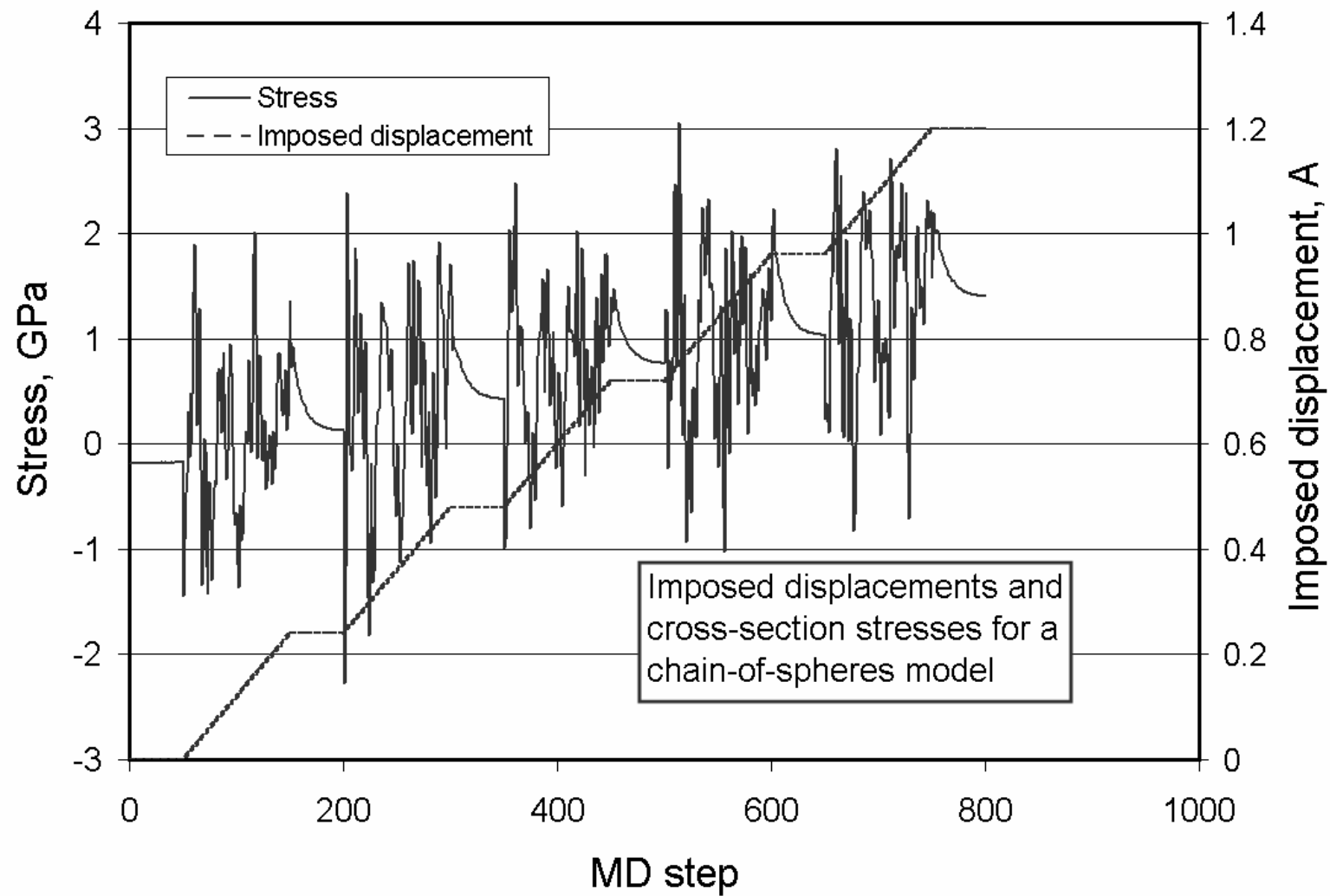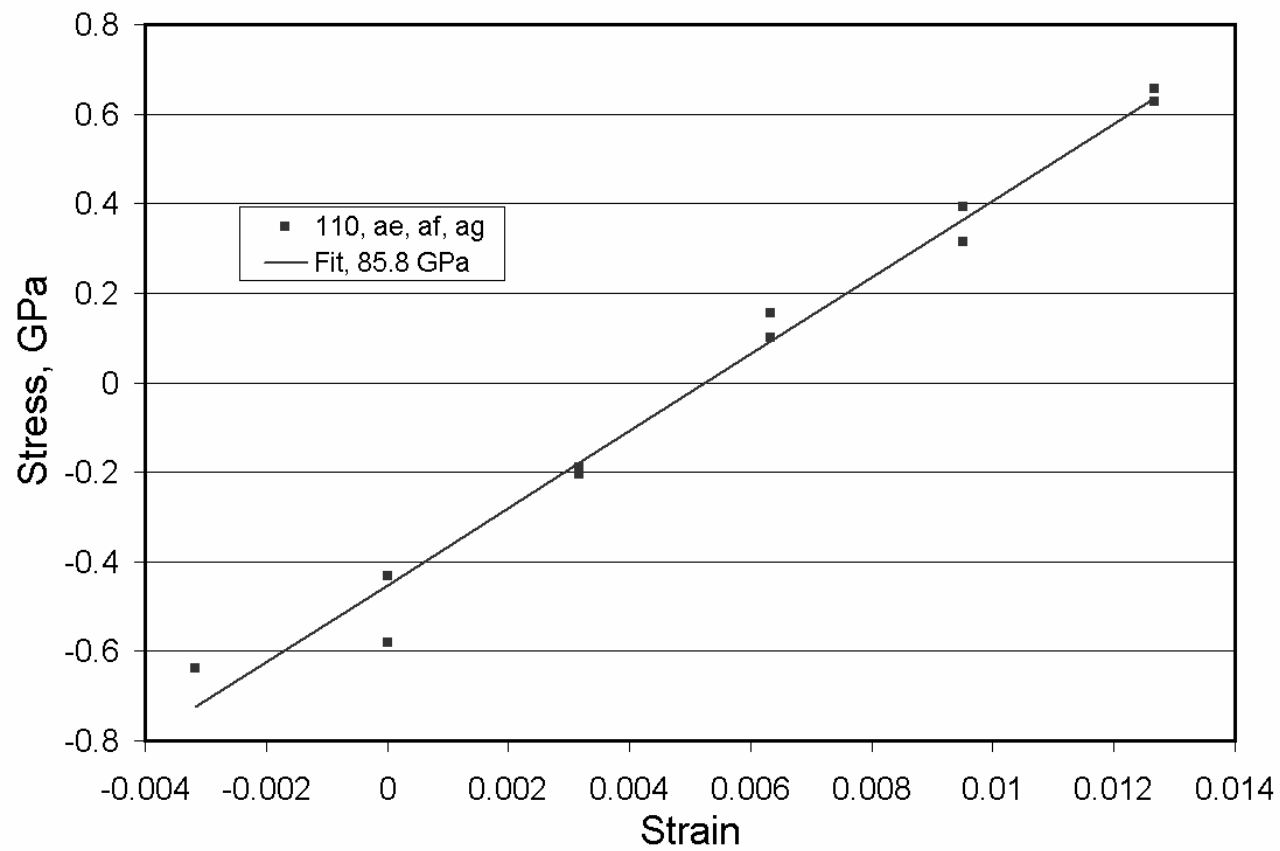

Perfect

Melt temp.
+ 1000 K

Solidified
block

Chain of
spheres

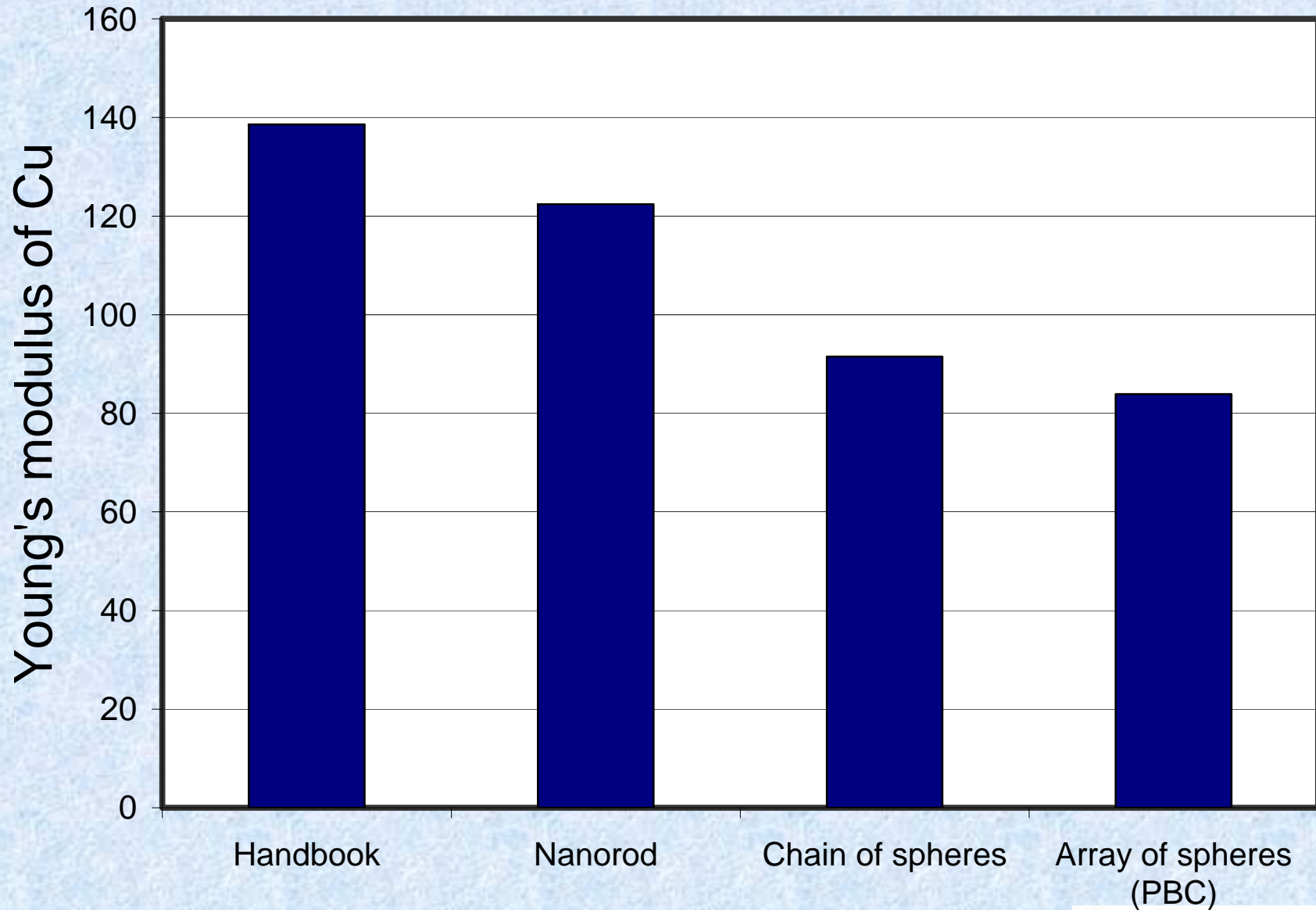# Modulus Deficit in Thin Film Copper Electrodeposits: Experiments and Modeling

Imposed displacements and cross-section stresses for a chain-of-spheres model

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Stress = F/A, av

Strain = dL/L

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